OFFICE OF SPACE SCIENCE AND APPLICATIONS

A STRATEGY FOR LEADERSHIP IN SPACE THROUGH EXCELLENCE IN SPACE SCIENCE AND APPLICATIONS

This report has been prepared as an internal OSSA document, and it will serve as the basis for OSSA program planning in the future.

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PREFACE

The program of the Office of Space Science and Applications (OSSA) today may be characterized as a program in transition—transition from the exhilarating pace of the 1960s, through the era of fewer, but more sophisticated, missions of the 1970s, to the current trend toward large, complex, long-duration missions that by their very nature require a more deliberate pace. Planning for major missions has evolved from discipline-specific research to a multidisciplinary approach to answering major scientific questions. Our progress over the last three decades has brought us to the point where the number and breadth of science and applications disciplines depending on OSSA resources have grown substantially, and technological advancement has generated great new opportunities that carry with them increasingly complicated methodologies. Space science and applications planning is evolving toward a new approach to the future—consolidated strategies to carry out flight research programs.

The Presidential Directive on National Space Policy, which was approved on January 5, 1988, reaffirms the long-standing call for U.S. leadership in space. With the number of spacefaring nations increasing, and with those nations making significant inroads into all areas of space science and applications, U.S. leadership is being challenged. Leadership requires that a nation have a clear vision of a desired future, articulated by specific goals and plans, and that it visibly demonstrate its accomplishments by the achievement of those goals and plans.

In the present environment, strategic planning of the OSSA program has become increasingly important. Integrating priorities across research disciplines while maintaining a balanced program of major, moderate, and small missions and supporting activities is imperative. In addition, plans for using the significant new opportunities offered by the Space Station Program must be developed. To establish a context for decision-making, to provide a common focus for all the elements of OSSA's program, and to maintain the program's viability, vitality, and flexibility, OSSA has initiated a strategic planning process.

OSSA has formulated a strategy that makes an appropriate contribution to achieving overall NASA goals, and that also directs the energies of OSSA and the institutions with which OSSA collaborates toward the realization of the specific goals and objectives of the disciplines within OSSA. The strategy also must be responsive to the guidance of the NASA Administrator, Congress, and OSSA's advisory groups, and to realistic projections of technology readiness, budget allocations, launch windows, availability of appropriate launch vehicles, and other resources.

The strategy is constructed around five actions: (1) establish a set of themes; (2) establish a set of decision rules; (3) establish a set of priorities for missions and programs within each theme; (4) demonstrate that the strategy can yield a viable program; and (5) check the strategy for consistency with resource constraints. The outcome of this process is a clear, coherent strategy that meets both NASA's and OSSA's goals, that assures realism in long-range planning and advanced technology development, and that provides sufficient resiliency to respond and adapt to both known and unexpected internal and external realities.

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INTRODUCTION

National Space Policy

The National Aeronautics and Space Act of 1958 established NASA's mandate to conduct activities in space that contribute substantially to the expansion of human knowledge and "to the preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere."

Three decades later, the Presidential Directive on National Space Policy, approved on January 5, 1988, similarly states that "a fundamental objective guiding United States space activities has been, and continues to be, space leadership."

Leadership in space can only be maintained through the active, continuing development of a vital scientific research and applications program, and through the visible and significant achievement of the objectives of that program. Accordingly, the new policy also states that some of the overall goals of the United States civilian space program are:

To obtain scientific, technological, and economic benefits for the general population

To improve the quality of life on Earth through space-related activities

To expand human presence and activity beyond Earth orbit into the solar system.

To achieve these goals, the policy puts forth the following objectives for civilian space activities:

To expand knowledge of the Earth, its environment, the solar system, and the universe

To create new opportunities for use of the space environment through the conduct of appropriate research and experimentation in advanced technology and systems

To develop space technology for civil applications and, wherever appropriate, make such technology available to the commercial sector

To preserve the United States preeminence in critical aspects of space science, applications, technology, and manned space flight

To establish a permanently manned presence in space

To engage in international cooperative efforts that further United States space goals.

The new policy serves to reinforce traditional OSSA goals and it signals the fact that the United States has adopted long-standing NASA goals. Our advancement of technology for space determines the horizons toward which space science and applications and the expansion of human presence can reach. Space science and applications have many specific goals serving both the needs and the curiosity of humanity. But space science itself opens new vistas of knowledge that are critical to the pursuit of human exploration of space. Pushing the frontiers of civilization deeper and deeper into space is simply the continuing manifestation of one of our most compelling traits—to ever explore. Yet even here, as we step farther and farther from Earth, we also serve the objectives of science, establishing new celestial observatories, learning to apply the environment of space to our needs, and exploring in detail the cosmic evidence of our origin and evolution.

OSSA Overview

The Office of Space Science and Applications is one of the program offices of the National Aeronautics and Space Administration. It is responsible for planning, directing, executing, and evaluating that part of the overall NASA program that has as its goal the utilization of the unique characteristics of the space environment to conduct a scientific study of the universe, to solve practical problems on Earth, and to provide the scientific research foundation for expanding human presence beyond Earth into the solar system. OSSA guides its program toward leadership through its pursuit of excellence in space science and applications across the full spectrum of disciplines. The drive for excellence, combined with the active achievement of program goals, firmly positions U.S. space science and applications for an exciting, productive future.

The efforts of the OSSA program result in increased knowledge for all humanity. The scope of these efforts ranges from the oceans and tectonic plates that make up our Earth to the upper reaches of our atmosphere, and from our solar system to other distant galaxies. The pursuit of these objectives results in the development of tools, techniques, and procedures that can use the vantage point or characteristics of space to aid in the solution of major national problems and to contribute to the economic health and development of the United States.

OSSA pursues these goals through an integrated program of ground-based laboratory research and experimentation; suborbital flight of instruments on airplanes, balloons, and sounding rockets; flight of instruments on the Shuttle/Spacelab system, on commercially developed facilities, and on the permanently manned Space Station; and the development and flight of automated Earth-orbiting and interplanetary spacecraft. The program is conducted with the participation and support of all the NASA Centers, other Government agencies and facilities, universities throughout the United States, and the aerospace contractor community, with substantial international participation in many aspects of the program.

The Office of Space Science and Applications includes seven program Divisions, each of which emphasizes and applies a different scientific discipline to successfully accomplish OSSA's goals. These Divisions and their roles are:

Astrophysics, which has the goals of understanding the origin and fate of the universe, and the birth and evolution of the large variety of objects in the universe, from the most benign to the most exotic; and of probing the fundamental laws of physics by examining the effects of extreme physical conditions on matter. The strategy for accomplishing these goals is based on contemporaneous observations across the entire electromagnetic spectrum.

Solar System Exploration, which has the goal of understanding the formation and current state of all the planets in the solar system, including Earth, and of the comets and other primitive solar system bodies.

Space Physics, which has the goals of understanding the origin, evolution, and interactions of particulate matter and electromagnetic fields in the upper atmospheres, ionospheres, and magnetospheres of the Earth and other planets; of understanding the Sun as a star and as a source of solar system energy and material; and of understanding the acceleration, transport, and interactions of energetic particles and plasmas throughout the solar system and the galaxy.

Earth Science and Applications, which has the goal of understanding the factors that influence the Earth's environment and the ways in which the total environment responds to those factors. This also involves using that knowledge to benefit humanity by predicting weather and storms, achieving a comprehensive understanding of ocean dynamics and processes, understanding terrestrial ecosystems and subsurface geophysical processes, and understanding the present and future chemical composition of the upper atmosphere and the influence of that composition on the long-term behavior of climate.

Life Sciences, which has the goal of understanding the origin, evolution, and distribution of life in the universe, the relationship between a changing Earth and an evolving biota, and the effects of the space environment on living systems. Special emphasis is placed on assuring that human beings can function effectively and safely in space, and on utilizing the unique characteristics of the spaceflight environment to conduct fundamental biological and biomedical research.

Microgravity Science and Applications, which has the goals of utilizing the unique characteristics of the spaceflight environment to conduct basic research in physics and chemistry, with special emphasis on materials science; of understanding the role of gravity in materials processing; and, where possible, of demonstrating the production of improved materials that have high technological utility.

Communications and Information Systems, which has the goals of developing technologies to assure that the United States is in a position to make optimum use of the unique advantages of space-based communications systems and of identifying and applying advanced communications and information systems technologies to meet the unique needs of the space science and applications program, the satellite communications industry, and the public sector.

A more detailed discussion of OSSA's scientific disciplines and their individual strategies is provided in the Appendix.

OSSA Goals and Objectives

Traditionally the focus of OSSA's activities, advancing scientific knowledge of the planet Earth, the solar system, and the universe beyond remains a major component of OSSA's future plans. OSSA has always directed its energy toward using the unique vantage point and environment of space to study the universe and to solve practical problems on Earth, and OSSA will continue to do so. In addition, many of OSSA's current and future efforts will directly support NASA's goal of expanding human presence beyond the Earth into the solar system by providing the scientific research foundation that is essential for planning major human initiatives. This research foundation will be built by characterizing the surfaces of the Moon and Mars, by assessing the potential for using nonterrestrial resources in space, by developing a scientific basis for understanding the long-term effects of the space environment on human beings, and by developing appropriate countermeasures to prevent or ameliorate these effects.

OSSA has established a number of near-term objectives that will guide its plans and programs for the future. These include (in no order of priority):

Complete the group of astronomical facilities ("Great Observatories"), which will observe the universe across the electromagnetic spectrum with unprecedented resolution and sensitivity.

Complete the phase of detailed scientific characterization for virtually all of the solar system, including the terrestrial planets, the primitive bodies, and at least the nearer parts of the outer solar system.

Quantitatively characterize the physical behavior of the Sun, the origins of solar variability, the geospace environment, and the effects of solar processes on the Earth.

Establish a set of observing platforms to study the Earth system on a global scale and to determine the long-term changes that can develop as a consequence of the interactions between the components of that system, in order to eventually develop the capability to predict changes that might occur, either naturally or as a result of human activity.

Determine, develop, and exploit the unique capabilities provided by the Space Station and other space-based facilities to study the nature of physical, chemical, and biological processes in a microgravity environment and to apply these studies to advance science and applications in such fields as materials science, plant and animal physiology, biotechnology, and fluid physics.

Develop the scientific foundation to support the planning of human exploration beyond Earth—information about the effects of low gravity and space radiation on humans, the nature of the surfaces of the Moon and Mars, and the potential for using nonterrestrial resources in space.

Develop and apply advances in communications and information systems technology to meet future needs in space science and applications, the satellite communications industry, and the public sector.

OSSA Principles

In the coming years, OSSA will continue to nurture the principles that have served it well in the past, including:

- ***Constant emphasis on excellence and the maintenance of U.S. scientific leadership***
- ***Basic scientific goals and strategies defined by the scientific community***
- ***Use of scientific peer review in all appropriate aspects of the program***
- ***Balance among the various scientific disciplines***
- ***Close communication with external scientific and applications communities, particularly in the advisory process***
- ***Strong support for universities to provide essential long-term research talents***
- ***Effective use of the NASA Centers in formulating and implementing the OSSA program***
- ***Choice of appropriate mission approach determined by scientific and applications requirements***
- ***Strong research foundation for space applications.***

Especially important in the past, and a major theme for the future, is the need for an increasingly interdisciplinary approach to major scientific problems. The importance of such an approach has become more compelling as the pursuit of solutions to major space research problems evolves to transcend some of the narrow and artificial boundaries between disciplines. Such problems cannot be solved without applying data and insights from many different fields. The future will see a continuing application of multidisciplinary approaches to such questions as the origin of stars and solar systems, the origin and evolution of life, the understanding of processes that cause all planets—especially the Earth—to form and change, and the gathering of the information needed to plan long-term human voyages beyond the Earth.

The OSSA Vision

OSSA envisions that, at the dawn of the 21st Century, we will have successfully pushed back the frontiers of space to further explore and understand the universe in which we live.

The four Great Observatories—the Hubble Space Telescope, the Gamma Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility—will be operating together to observe the universe across the entire electromagnetic spectrum. With the information these observatories reveal to us, we will gain a deeper understanding of our role and our place in the universe. The revolution that this understanding will cause in our thinking will rival the one that occurred when an earlier astronomer, Copernicus, showed that the Earth was not the center of the universe. Many totally unexpected scientific discoveries will be made; nature, unfettered by the limitations of human imagination, will continue to surprise us.

Our way of thinking about our uniqueness in the universe will change. We will have good estimates of how many stars have planetary systems and we will have an image of at least one planet in orbit around a star other than our Sun.

The question of whether the universe is expanding indefinitely, or will at some time begin to contract should have been answered. The distance scales and the rate of expansion will be known with much better precision. Theorists, by combining data from the Great Observatories with experiment results from Earth-based particle accelerators, will develop models for the origin and fate of the universe that include unification of physical laws. Our understanding of the laws of physics will be undergoing revision to accommodate new insights gained from studies of relics from the creation of the universe and from observations of matter reacting to pressures and magnetic fields unimaginable in the vicinity of the Earth, but common near compact objects such as neutron stars and black holes.

We will have determined the form of the 90 percent of the matter, currently of unknown form, that constitutes the near and far universe. This matter may be composed of new fundamental particles such as "axions" and "photinos," or of new classes of astronomical objects such as brown dwarfs, or of unexpected concentrations of hot, pervasive gases.

The Observatories will be visited by the Space Shuttle and the Orbital Maneuvering Vehicle for routine servicing and instrument exchange, and will be taken into thermal protectors at the Space Station for more extensive servicing. Scientists, from workstations at their universities, will browse astronomical data from the Observatories, and data sets with appropriate analytical software on optical disks will be quickly and conveniently accessible. The combination of data from the entire electromagnetic spectrum will be used to build a total physical understanding of exotic phenomena such as quasars and supernovae. Our nation will be perceived as leading a worldwide effort to understand the place of humanity in the universe.

Robotic spacecraft will have flown past all the planets and moons of our solar system, except Pluto and Charon, sending back the images that fill the world with awe and wonder and that build a solid foundation of scientific understanding. We will have orbited every major solar system body that is accessible to us. The surface of Earth's sister planet Venus will have been mapped, substantially augmenting the information base necessary for comparative study of the terrestrial planets: Mercury, Venus, Earth, Mars, and the Moon. The history and future of our own planet will have become clearer through our increased understanding of our solar system neighbors.

The Moon's global surface mineral and elemental composition will have been measured, and an assessment of its resources, including a search for frozen volatiles at the poles, will have been completed. Combined with what we have already learned about the Moon, this information will help to prepare for the return of human beings to the Moon to build an outpost on which we can explore and exploit the resources of Earth's neighbor.

Mars, the only other planet besides Earth with the potential for human habitability, will have been studied again to determine its geochemistry and climatology. These studies will help in the development of plans for a human expedition to Mars, a journey that will expand human presence farther into space than it has ever been before.

We will have peered back into the early history of the solar system by studying its most primitive, unaltered bodies—comets and asteroids. A spacecraft will have flown in formation with a comet, and studied an asteroid at close range. We will have executed solar system mission trajectories to fly by asteroids whenever possible, to reconnoiter the resources these primitive bodies may hold.

Traveling farther into the outer solar system, we will be orbiting Saturn and will have released a probe into Titan's thick, murky atmosphere, and sensed its surface with radar. In the atmosphere of this largest moon of Saturn, a complex process of chemical evolution has occurred and continues to occur. Studying this evolution can teach us much, for it may be repeating some of the earliest steps in the processes that led to the appearance of life on Earth.

Closer to home, we will have been receiving information about our own planet for several years from the Earth Observing System and a variety of other instruments in space. Combined with ground-based measurements and observations, this information will advance our understanding of the Earth system on a global scale. We will have begun to make progress toward describing how Earth's intimately connected component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales. Earth system science will be on the way to developing the capability to predict those changes that will occur in the future, both naturally and in response to human activity.

Measurements taken over a long, continuous period of time, from the unique perspective of low-Earth orbit, will have enabled us to begin to quantify and understand global change on our planet. The nature and dynamics of the myriad components of the Earth system—core, mantle, crust, Earth's solid surface, soils, and land masses, vegetation and forestation, oceans, cloud cover, and the layers that comprise the atmosphere—will have been observed and measured. The information generated will have been integrated into a comprehensive data system that scientists can access and use to understand and describe the global character of Earth.

The knowledge gained through Earth observations will provide continuing benefits to humanity. Our predictive ability will have brought us closer to being able to alleviate some of the detrimental effects of climatological and geological occurrences. We will have begun to achieve a comprehensive understanding of ocean dynamics and processes by determining the three-dimensional structure of the planet's ocean currents. An improved understanding will have been gained of the coupled chemistry and dynamics of the stratosphere and mesosphere, the role of solar radiation in these processes, and the susceptibility of the upper atmosphere to long-term changes in the concentration and distribution of key atmospheric constituents, particularly ozone and the greenhouse gases. By coming to understand Earth's present condition, perhaps we will have developed techniques to safeguard its future.

The Sun that gives us light and sustains life on our planet will have been studied both as a star and as the dominant source of energy, plasma, and energetic particles; we will have better determined the effects of solar processes on Earth. We will have begun to understand the Sun's interior and the origin of the solar wind, and we will have flown multiple spacecraft in close coordination to measure the total energy budget of plasma processes in Earth's magnetosphere. A probe from Earth will be speeding toward the inner heliosphere, the unexplored region between 4 and 60 radii from the Sun, where the solar wind first flows at supersonic speeds. We will have begun to have the capability to predict the behavior of this star, most central to the destiny of our solar system and of humanity. The quantitative study of the geospace environment, the area between Earth's surface and high-Earth orbit, will be progressing toward a full-scale predictive stage. We will be well on our way to understanding how the complex plasma phenomena in different regions of the solar system and the Milky Way Galaxy are related to the characteristics of the larger systems themselves.

We will know and understand the effects of long-duration spaceflight on our most precious of resources, human life. We will have completed an evolutionary study—starting with data gathered on Skylab, to the Space Shuttle, through Spacelab, to the Space Station—of the reaction of biological systems, including human beings, to low gravity and space radiation. We will have determined and developed measures to ameliorate or prevent the physiological and psychological results of long-term exposure to the space environment, and of the relative isolation that space travel necessarily imposes on our explorers.

Hand in hand with academia and industry, we will have determined, developed, and begun to exploit the unique capabilities provided by the Space Station and other space-based facilities to study the nature of physical and chemical processes in a microgravity environment and to apply these studies to advance science and applications in such areas as materials science, combustion science, medicine, biotechnology, and fluid physics. The Space Station, an operational national laboratory, will enable great strides in microgravity research.

Advanced communications technologies and information management and computational facilities will be operating to support the transmission, acquisition, archiving, and analysis of the tremendous volume of data that will be returning from instruments in space. These capabilities will be orders of magnitude faster and more efficient than systems in use today, allowing an acceleration in progress toward achieving our goals.

In universities, industries, and federal laboratories, scientific research and analysis of these data will be proceeding at a pace commensurate with our exploration. The research conducted in our scientific laboratories will continually yield new insights to prove, disprove, or apply our theories. The success of our space program will be a source of great national pride, and it will attract our youth in ever-greater numbers to develop the skills and knowledge that will be needed to carry on the program in the future. Other nations will be drawn to participate with us in our accomplishments; perhaps old rivalries will be set aside for the sake of the mutual benefits to be gained by joining forces for scientific advancement.

The basic premise of strategic planning is to develop a clear vision of a desired future; this is OSSA's vision. The strategy for realizing this vision is necessarily ambitious, yet it is firmly tempered to be realistic enough to succeed. Our vision sees NASA and the United States enjoying an exciting and productive era in space science and applications, with leadership in space manifested by visible achievements that are second to none.

THE OSSA STRATEGY

To chart a course for an enduring program to make its vision a reality, OSSA has formulated a strategy that is the culmination of extensive interaction and collaboration with the scientific and applications communities, careful consideration of resource guidelines, and iterative reviews of pertinent issues and challenges.

The OSSA strategic approach is constructed around five actions:

1. ***Establish a set of programmatic themes.***
2. ***Establish a set of decision rules.***
3. ***Establish a set of priorities for missions and programs within each theme.***
4. ***Demonstrate that the strategy can yield a viable program.***
5. ***Check the strategy for technology readiness and for consistency with resource constraints, such as budget, manpower, and launch vehicle availability.***

Each of these actions is described in more detail below.

Taken together, these five actions define a programmatic process by which OSSA will plan its activities and allocate its resources. The programmatic themes provide direction and balance to our program, the decision rules guide us in choosing efforts among and within programmatic themes, and the list of priorities determines the order in which we will pursue the missions and programs within each theme. By exercising these actions, various plans for an integrated OSSA program result and these plans can be checked to determine whether they yield a viable program and are consistent with our resource constraints.

An important point to note is that exercising the above actions does not, nor is it intended to, result in a single plan. Rather, these actions define a realistic and flexible process that will provide the basis for making near-term decisions on the allocation of resources for the planning of future efforts. The least certain constraint on our planning is the budget level that will be available to

OSSA. The process defined here allows us to adjust to varying budget levels, both those levels that provide opportunities for an expanding science and applications program and those that constrain growth.

In developing this strategy, we have assumed that the overall NASA budget will continue to grow to accommodate overall Agency plans for the Shuttle and expendable launch vehicles, the Space Station, and the basic research and technology program, and that OSSA will receive a proportion of the overall budget that is consistent with its historical allocation. Further, we assume the implementation of current plans for a mixed fleet of launch vehicles, with the launch rates presently projected for the Space Shuttle and for expendable launch vehicles. (In general, expendable launch vehicles will be used for payloads that do not require crew intervention or other capabilities unique to the Space Shuttle.) The level of availability of the Agency work force is assumed to be consistent with Agency plans.

Overarching Agency initiatives, such as geostationary platforms as part of the Mission to Planet Earth, extended-duration Space Station crew certification, and/or Mars Rover/Sample Return as a precursor to human exploration, are not considered in the base strategy. If such initiatives are approved, the appropriate resources must be added over and above the baseline.

Finally, in developing the strategy, no explicit assumptions are made about dependence on international cooperation. Instead, we intend to define our strategy and then to go forward and seek opportunities for international cooperation to fit our plans.

Within these guidelines and assumptions, five basic themes drive the development of OSSA's strategy.

Programmatic Themes

The Ongoing Program

First and foremost, for missions in the ongoing program, the scheduling, resource allocations, and manifested slots on the Space Shuttle or an expendable launch vehicle must be protected and assured. The same high level of priority applies to ongoing research programs and mission operations and data analysis activities.

Leadership Through Major and Moderate Missions

OSSA plans to move boldly forward to make fundamental and visible advances in key areas of space science, to ensure that our world leadership is preserved in the future. Because they provide the largest quantum leaps in the advancement of scientific knowledge and technological ability, our pursuit of leadership is most conspicuous through major and moderate missions.

Increased Opportunity with Small Missions

Small missions are vital to the program because they can be accomplished relatively inexpensively, allowing the consideration of more innovative ideas, and they can be conducted on a short time scale, offering quick turnaround and continuing opportunity. The small missions are particularly important for the training of the next generation of scientists and engineers, since the missions are of a size that universities can develop, and the development and flight of small missions can occur in the same period of time as that required to earn a graduate degree.

The Transition to Space Station

Beginning with Spacelab and other in-space facilities, it is time to move aggressively, but sensibly, to develop the principal areas of space science and applications that will take advantage of unique Space Station opportunities, such as pressurized laboratories for microgravity science and life sciences research, the multidisciplinary use of attached payloads, and polar platforms for Earth science research.

The Research Base

The research and analysis program provides base support for a vigorous and productive research community and it presents a special opportunity for students to develop the skills that will enable them to conduct the programs of the future. Parts of the program need early enhancement, especially in the replacement of aging laboratory equipment, in the increase of theory and data analysis funding in certain disciplines, and in the ground-based and suborbital programs.

Decision Rules

The first step in the process of determining mission priorities and sequence is the establishment of a realistic budget level. Then, the five themes described earlier provide a template on which the OSSA program is built for 1989 and succeeding years. Ideally, at least one new initiative for each theme, excepting the ongoing program, would be included each year, and we would systematically pursue each item under each theme, in sequence by priority. However, in the event that the budget or other aspects of the external environment do not accommodate simultaneous enhancements in all four areas, certain rules have been formulated to determine the mix of program elements.

Complete the Ongoing Program.

The completion of the ongoing program always has the highest priority; no resources allocated to those programs already under way will be sacrificed or postponed in order to pursue new starts.

Initiate a Major or Moderate Mission Each Year.

Major missions preserve and enhance U.S. leadership in key areas of space science and applications and we will pursue major missions whenever available resources allow us to do so. If an assessment of foreseeable expenditures for candidate missions, over both the near term and the lifetime of the program, indicates that our resources do not permit a major mission, we will pursue a moderate mission.

Initiate Small Missions in Addition to Major or Moderate Missions.

In all cases, we endeavor to start a small mission or a small mission program every year, in conjunction with either a major or a moderate mission.

Move Aggressively, but Sensibly, to Build Science Instruments for the Space Station.

Space Station initiatives are determined by scientific discipline pace and balance, relevance to Space Station, and technological maturity. We will move forward systematically to provide a complete set of fully developed facilities and instrumentation for the Space Station.

Research Base Augmentations Will Be Sought Whenever They Are Warranted.

They are determined by the impact of the rest of the program on discipline stability, progress, and future needs.

The Plan for 1989

The five programmatic themes and the rules for decision-making were followed in the construction of our plan for 1989, which is detailed below.

ONGOING PROGRAM

First, the 1989 plan includes sufficient resources to keep each of the ongoing flight programs on schedule for launch in their manifested slots on the Space Shuttle or an expendable launch vehicle. The long hiatus in space science and applications launches is drawing to a close. In what promises to be an exciting year, 1989 is expected to see the launch of the Cosmic Background Explorer, the Magellan mission to Venus, the Hubble Space Telescope, the Astro Spacelab mission, and the Galileo mission to Jupiter. In August of that same year, Voyager 2 will encounter Neptune, a major milestone in outer solar system exploration, and one that will surely return a wealth of scientific information.

Development will continue on an impressive array of major, moderate, and small missions to be launched from 1990 through 1993, including:

Gamma Ray Observatory
Roentgen Satellite
Combined Release and Radiation Effects Satellite
Ulysses
Laser Geodynamics Satellite
Extreme Ultraviolet Explorer
Ocean Topography Experiment (TOPEX)
Upper Atmosphere Research Satellite
Advanced Communications Technology Satellite (subject to action on the FY 1989 budget)
Wind
Geotail
Mars Observer
Polar
Mobile Satellite
Spacelabs, including a series of Space Life Sciences missions; International Microgravity Laboratory and U.S. Microgravity Laboratory missions; several Atmospheric Laboratories for Applications and Science; two Astronomy Laboratory missions; and two flights of the Space Radar Laboratory.

In addition to the flight projects, resources that support ongoing program elements in research and analysis, suborbital observations, theory and modeling, laboratory and supporting observations, and mission operations and data analysis for ongoing operating missions will continue uninterrupted.

LEADERSHIP: MAJOR AND MODERATE MISSIONS

Our plan makes a bold statement that the United States will pursue world leadership in space science in 1989 through an initiative in astrophysics. Our nation is poised for an accomplishment unique in the history of humankind—to observe the physical universe with unprecedented completeness and resolution. We have the demonstrated capability to construct high-technology orbiting telescopes that can observe the universe in all forms of electromagnetic radiation, and we have the unique capability with the Space Shuttle, and eventually the Space Station, to maintain these telescopes on orbit.

The key to realizing this ambition is the Advanced X-Ray Astrophysics Facility—a telescope facility designed to observe the universe in the X-ray region of the electromagnetic spectrum. This facility will be 100 times more sensitive and have 1,000 times more capability for spectroscopy than any previous or planned X-ray mission.

The Advanced X-Ray Astrophysics Facility is to fly in concert with the Hubble Space Telescope, which will observe the universe in visible and ultraviolet radiation; with the Gamma Ray Observatory, which will observe in gamma rays; and with the Space Infrared Telescope Facility, which will observe in the infrared region. These Great Observatories, operating together, will provide a comprehensive physical picture of the universe's most enigmatic objects, and will observe the full range of phenomena in the universe, from the most tranquil to the most violent.

The Advanced X-Ray Astrophysics Facility will also provide a scientific opportunity that is unlikely to be repeated for many generations. The closest supernova to occur near Earth since the invention of the telescope 400 years ago was seen last year, and it can be studied by the facility, provided that launch occurs by 1995, before the X rays fade. Supernovae are responsible for the origin of all the heavier elements in the universe, including those essential for life. In this era in which United States leadership in space is being challenged, our plans assert that in the premiere scientific discipline of astrophysics, we will be second to none.

SMALL MISSIONS

To maintain program continuity and vigor through frequent flight opportunity for small missions, our plan proposes an augmentation to the Explorer program that builds on the augmentation that Congress provided last year. A clear and present need exists to stimulate the research community, particularly at universities, with exciting new opportunities, which will attract new scientists and engineers to space science. Historically, the Explorer program has been one of the means by which we have provided such opportunities, through frequent launches of focused science missions.

Accordingly, we are planning to augment the Explorer program to allow for more small missions, which can be launched on Scout-class expendable launch vehicles. These missions are sufficiently small that they can be built and launched within three years, yet they are sufficiently capable to accomplish first-class scientific objectives in astronomy, space physics, and upper atmospheric physics. We anticipate shortly releasing an Announcement of Opportunity to select these missions, and we expect that this opportunity will provide yet another indication that the space program is moving forward again.

SPACE STATION UTILIZATION

The fourth theme of our 1989 plan concerns the Space Station. It is time to begin to aggressively develop the principal areas of space science and applications that will take advantage of the unique opportunities that the Space Station will provide us. Four such areas—microgravity science, life sciences, multidisciplinary attached payloads, and Earth science from the Polar Platform—are being developed, and we have a separate strategy for each area.

The Space Station will provide us with a laboratory in which, with continual human interaction, we can conduct a broad range of microgravity experiments in materials science, fluid physics, and biotechnology. These experiments will advance our knowledge of basic physics, chemistry, and biology, and will have direct applications to improving our understanding of processes that occur on the Earth and in space.

To use the Space Station as a laboratory, we will develop six facilities: (1) a Space Station Furnace Facility, (2) a Modular Combustion Facility, (3) a Fluid Physics/Dynamics Facility, (4) a Modular Containerless Processing Facility, (5) an Advanced Protein Crystal Growth Facility, and (6) a Biotechnology Facility. We will fly elements of these facilities in advance of the Space Station, both to test and perfect the design of the facilities, and to provide new research results in the important discipline of microgravity science and applications.

The plan for microgravity science provides for the full development of all six facilities required for the Space Station, and allows for their test flight on a Spacelab mission and/or a commercially developed space facility. The program leads to the full instrumentation of the Space Station for microgravity science by the time of man-tended capability.

Life sciences research is also an important activity that we will conduct on the Space Station. We have ongoing studies on precisely how we will accommodate the life sciences research on the Space Station, and we are developing one of the facilities that we are certain we will require on the Space Station – the 1.8-meter centrifuge, which is essential to any biological research in space. As with the microgravity facilities, the centrifuge will be flown and tested on a Spacelab and/or a commercially developed space facility, and will then be transitioned to the Space Station.

Attached payload opportunities, which can be used by a broad range of science and applications disciplines, are also provided by the Space Station. Our strategy in this area is to begin with attached payloads that are not overly demanding on the environment and pointing capabilities of the Space Station; then, as we learn to use the Station and its full capabilities, we will evolve into using more sophisticated attached payloads. We anticipate shortly releasing an Announcement of Opportunity soliciting proposals for attached payloads to be carried on the Space Station during its initial one to three years of operation, and proposals for the definition of more ambitious investigations for possible attached payloads to be flown at a later time.

The Polar Platform of the Space Station provides us with the opportunity to make detailed observations of the Earth, of how it is evolving on a global scale, and of how we humans are influencing that evolution. We have recently released an Announcement of Opportunity, jointly with the Europeans and the Japanese, to select investigations for the Earth Observing System, which is to fly on the Polar Platform, and to select potential manned base attached payloads in the Earth sciences discipline. Our plan also includes the resources to conduct advanced technology studies to define instruments and information systems for the Earth Observing System.

The four parts of our Space Station initiative – the development of microgravity facilities, the development of the centrifuge and the planning for other life sciences facilities, the development of attached payloads, and the selection and study of Earth observing instrumentation for the Polar Platform – form a comprehensive plan to begin to make full use of the unique opportunities that the Space Station will provide.

RESEARCH BASE

The fifth and final theme of our plan for 1989 concerns the Research and Analysis program, which is the vital underpinning to our program. We are proposing to augment this program to continue our rocket and balloon campaign to understand the recent supernova, in advance of when it can be observed and studied by the Great Observatories; to complete the purchase of a new high-flying Earth remote sensing aircraft; and to provide additional resources to take maximum advantage of the upcoming encounter of the Voyager spacecraft with Neptune. The plan provides for continuing advanced technology development on the Mariner Mark II missions, Comet Rendezvous Asteroid Flyby and Cassini. We are also planning to begin development of a network of signal processing equipment to be attached to radio astronomy facilities to begin, in 1992, to search for other intelligent life in our galaxy. Detection of life elsewhere in the universe may be the most profound event to occur in human history.

With a clear eye toward the next five years, the plan for 1989 allows us to make significant progress toward achieving our ultimate goals. The U.S. space science and applications program has historically produced an outstanding scientific return on America's investment, and we expect this to continue and grow through the implementation of our five-year strategy, described next.

Five-Year Strategy

Beginning with the overarching goals of NASA as articulated by National Space Policy, and working through OSSA's goals and objectives, the themes and decision rules cited earlier form the basis for our strategy for the years 1990 through 1994.

ONGOING PROGRAM

Through each succeeding year, the flight projects and research programs started the previous year combine with those that are still under way to form the ongoing program. In all cases, the highest priority of OSSA's strategy is to carry out the ongoing program.

LEADERSHIP: MAJOR AND MODERATE MISSIONS

All the major flight projects in the 1989 ongoing program will be launched by 1993; a new major flight project requires four to six years to develop. Thus, to pursue leadership in key areas, the necessary next step is to select the successors to the ongoing program. Several criteria drive decisions about the selection and sequence of major and moderate missions. First, we want to pursue missions of the highest scientific priority, as identified by the National Academy of Sciences and the NASA Advisory Council. Second, the several candidate missions that fall within this category are assessed for the degree of technological readiness to pursue them; this determines the degree of understanding of cost and schedule risk for these candidates. Third, the order in which major and moderate missions are pursued is governed by the need to pace the implementation of discipline-specific plans at a rate of approximately one major or moderate new start every five years in each discipline; this pace keeps all the discipline programs moving forward and maintaining vigor. Finally, the missions are viewed in the context of the NASA Space and Earth Science Advisory Committee's recommendations for mission selection that are elucidated in the report *The Crisis in Space* *and Earth Science*. The report describes guidelines for the following criteria: (1) scientific merit, (2) programmatic considerations, and (3) societal and other implications.

Another guideline is that there should be one major or moderate new start per year. While we recognize the fact that circumstances may present occasions where more than one new start is possible, and others where no new start is possible, an average pace of one per year is necessary to meet the goals of leadership in key areas and to assure vigor and continuity. On the other hand, given a realistic estimate of resource constraints, more than one new start per year cannot ordinarily be expected, because available resources for small missions and for research and analysis must be preserved. Accordingly, the sequence of major and moderate missions in our five-year strategy has been determined as detailed below.

According to the decision rules, whenever resources permit, we will pursue major missions in order to preserve and enhance U.S. leadership. These major missions, in order of priority, are described below.

JOINT INITIATION OF COMET RENDEZVOUS ASTEROID FLYBY AND CASSINI MISSIONS

The Comet Rendezvous Asteroid Flyby (CRAF) mission will include a close flyby of a main belt asteroid followed by an extended multiyear rendezvous with a short-period comet, permitting detailed study of the comet's nucleus, dust, and atmosphere at close range under both quiescent and active conditions. The Cassini mission, a potential cooperative project with the European Space Agency, will conduct a comprehensive scientific investigation of the planet Saturn, its rings and moons, the surface and atmosphere of its principal moon, Titan, and the nature of fields and particles in Saturn's magnetosphere.

These two missions have long been established as endeavors of high scientific priority, because they combine to address the fundamental OSSA goal of determining the origin and evolution of the solar system and of life. The large planets preserve unprocessed elemental and isotopic abundances; scientists believe that in Titan's atmosphere, chemical and physical reactions similar to those that led to the origin of life on Earth may now be taking place. The primitive bodies, comets and asteroids, preserve relatively unprocessed molecular and organic material from the interstellar medium and the solar nebula. Studying the outer solar system and the primitive bodies provides information about the early history of the solar system, and about the origin, evolution, and distribution of prebiotic organic materials.

Because of this shared scientific goal and the complementary nature of the two missions' objectives, and also because both missions use the same Mariner Mark II spacecraft design, CRAF and Cassini are combined for a joint program. We place this initiative as the highest priority for major missions because development must be started now to assure a robust solar system exploration program at the end of this century. This approach assures the continued strength of the program, and continues our tradition of leadership in exploring the outer solar system.

THE EARTH OBSERVING SYSTEM

The Earth Observing System will place a suite of instruments in low-Earth orbit to make comprehensive observations of Earth's atmosphere, oceans, land surfaces, and biota. An integral part of the program is the collection, processing, analysis, interpretation, and archiving of the resulting data. The Earth Observing System is the centerpiece of NASA's implementation of the Earth System Sciences Committee strategy for integrated study of the Earth and of global change. Long-term, consistent measurements are required to understand global changes, and so, for at least 15 years, the mission will study the global-scale processes that shape and influence Earth as a system.

This study of global change on Earth is fundamentally important to humanity's future on this planet. We must apply the capabilities that we have developed in space to understand our own world, and to safeguard that world for the coming generations.

The Earth Observing System is recommended for an early start in order to address the accelerating need for information about the rapid evolution of Earth's environment, and to prepare to make timely use of platforms provided by the Space Station. Definition studies are expected to be completed in 1990 and a development start should follow as soon as possible.

THE SPACE INFRARED TELESCOPE FACILITY

The fourth Great Observatory, the Space Infrared Telescope Facility is a long-lived, meter-class, cryogenically cooled, infrared observatory to study the very cold regions of space. It will be launched by the Space Shuttle and serviced by the Shuttle and the Space Station. Regions and objects the facility will study are: locations where the cosmic gas and dust condense into stars; cool objects in the solar system—planetary systems, asteroids, and comets; and infrared-emitting extragalactic objects. It will be 1,000 times more sensitive than the Infrared Astronomical Satellite. One of its major applications will be to obtain detailed infrared spectrometry of the faint infrared sources that the Infrared Astronomical Satellite discovered but could not observe in detail. The Astronomy Survey Committee of the National Academy of Sciences has treated the Space Infrared Telescope Facility as a high-priority mission.

The four Great Observatories—the Hubble Space Telescope, the Gamma Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility—will provide world-class facilities for observing in all the major wavelength bands. Together, the Great Observatories will ensure U.S. leadership in astronomy and astrophysics for decades to come.

THE SOLAR PROBE

The Solar Probe will be humanity's first direct exploratory venture to the vicinity of the Sun. It will study the unexplored region between 4 and 60 radii from the Sun, where the solar wind begins to flow at supersonic speeds. The Solar Probe will measure the electromagnetic fields and will study the particle populations in the region close to the Sun. It will make fundamental measurements relating to stellar internal structure, gravitation, and relativity, and it will observe the structure of the solar atmosphere from the photosphere to the corona with exceptionally high spatial resolution.

Because the Solar Probe offers a unique opportunity for leadership in exploration of the heliosphere, and because it has been cited by the scientific research community as a high-priority objective, it has been established as the fourth major mission in our five-year plan.

In the event that resources do not permit the implementation of a major mission, the moderate missions described below will be pursued in order of priority.

HIGH-RESOLUTION SOLAR OBSERVATORY

The High-Resolution Solar Observatory is a scientific platform for performing investigations of the Sun's fine-scale magnetic structures. Its scientific objective is to study in visible light, and at the limits of spatial and temporal resolutions at which they actually occur, the fundamental magnetohydrodynamic processes of the Sun's surface atmosphere. This program has repeatedly been endorsed as the highest priority of the U.S. space solar physics discipline and, as such, has received the highest recommendations by the relevant committees of the National Academy of Sciences.

THE LUNAR OBSERVER

The second mission in the Planetary Observer program, the Lunar Observer will be constructed from Mars Observer spares to conduct a one-year polar mapping mission to measure the Moon's global surface mineral and elemental composition, to assess global resources (including frozen volatiles at the poles), to measure surface topography, and to measure magnetic and gravitational fields. In addition to the valuable scientific information that this mission will provide, the data from the Lunar Observer will contribute to the Agency goal of preparing the way for a possible human outpost on the Moon. In order to efficiently and cost-effectively make the transition to the Lunar Observer using spares from the Mars Observer, the Lunar Observer must begin in 1992. Therefore, at that time, the Lunar Observer will become the highest priority moderate mission, even if the High-Resolution Solar Observatory has not been started.

GRAVITY PROBE-B

Gravity Probe-B is designed to be a cornerstone test of general relativity. Einstein's universally accepted theory of special relativity ties together the structure of time and space. His theory of general relativity, which is far less thoroughly tested, ties together space, time, and gravity. This theory is on a much less secure experimental footing than the special theory, and alternative hypotheses exist. Gravity Probe-B will measure both the distortion of the "fabric of space time," imposed by the Earth's presence, and the subtle dragging of this fabric, predicted to result from the Earth's rotation. The influence of these effects will be seen in subtle precessional changes affecting the behavior of a set of four ultra-precision gyroscopes operating in a drag-free, superconducting environment. The required technology for this demanding undertaking has been under development since 1965. The key elements will be tested using a functioning prototype to be flown on a Space Shuttle flight prior to the science mission.

SMALL MISSIONS

The missions in this category are essential to sustaining the vigor of our program. They can be launched more frequently than major or moderate missions, perhaps as often as every two years per discipline. The small missions can provide opportunities comparable to classical Explorers.

Currently identified small missions of the five-year strategy include:

EARTH PROBES

To complement the observations carried out by the Earth Observing System, we have defined a series of Explorer-class missions in Earth science, called Earth Probes. We plan a continuing series of these missions to be launched at a regular interval. For example, the Tropical Rainfall Measurement Mission, the Magnetic Field Explorer, and the Geopotential Research Mission are concepts for small missions that may be selected as Earth Probes.

LIFESAT

Lifesat is a small, recoverable, and reusable orbiting spacecraft that can be used as an inexpensive platform for conducting life sciences (and possibly other) experiments. The spacecraft can be launched on a variety of expendable launch vehicles and can provide up to 40 days of microgravity environment. This program provides a particularly attractive opportunity for multinational cooperation.

SPACE STATION UTILIZATION

For this segment of our five-year strategy, we wish to initiate the space biology counterpart to the 1989 microgravity initiative. The goal of space biology research is to use the unique characteristics of the space environment, especially microgravity, to increase our understanding of life and its processes, and to understand how gravity affects and has shaped life on Earth. The objective of the research, which encompasses both plants and animals, is to understand the mechanisms by which organisms perceive gravity and transmit the information to a responsive site, to determine the role of gravity in reproduction, development, maturation, and function, and to understand the mechanisms by which environments in conjunction with microgravity affect living systems.

The development of second-generation attached payloads for a variety of disciplines will also need to begin during this five-year period.

A key factor in OSSA's preparation for the Space Station will be the continued use of Spacelab, the Space Shuttle mid-deck lockers, and other appropriate carriers to develop, test, and verify new and improved instrumentation for subsequent use on the Space Station.

RESEARCH BASE

The highest priority in this area is to augment the research and analysis base that is essential to OSSA's program. In particular, laboratory equipment and facilities need to be upgraded, and enhancements in funding need to be provided for new instrument development, more capable information systems and computational facilities, data analysis, and theoretical studies. Further, the suborbital program needs enhancement in balloons and rockets and in areas such as those described below.

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

SOFIA is a 3-meter-class telescope planned to be flown in a modified Boeing 747 airplane to observe the Infrared Astronomical Satellite sources with good angular resolution at infrared wavelengths inaccessible from the ground. A facility with tremendous potential for science, SOFIA can offer an improvement in resolution over the 0.9-meter Kuiper Airborne Observatory, it can be readily available to the scientific community (with a short turnaround time), and it can be flown on a reliable, reusable vehicle. Since the Space Infrared Telescope Facility will not fly until the late 1990s, SOFIA will allow us to follow up on the exciting discoveries of the Infrared Astronomical Satellite in the interim, and SOFIA will complement the Space Infrared Telescope Facility when it becomes operational.

NEW AIRCRAFT FOR EARTH REMOTE SENSING

Observations of Earth from instrumented aircraft complement those taken from space and on the ground, and provide critical flight demonstration tests of advanced remote sensing technologies. Currently, four aircraft—one DC-8, two ER-2s, and a C-130—make up the means of conducting this program. Since aircraft observations provide a method for uncomplicated launch and fast turnaround, we wish to update the fleet with more capable and more sophisticated craft.

Summary

The chart below graphically represents the strategy that will guide OSSA's plans from 1989 through 1994. The strategic approach described earlier, including consistent programmatic themes and decision rules, will continue to provide a methodology for OSSA strategic planning in the future.

	Ongoing Program	**Major & Moderate Missions**	**Small Missions**	**Space Station Utilization**	**Research Base Enhancements**
1989	Research and Analysis Mission Operations and Data Analysis Flight Projects Spacelabs and Other Carriers	AXAF	Scout-class Explorers	Microgravity Facilities 1.8m Centrifuge Attached Payloads Eos Payload Definition	SETI Microwave Observing Project CRAF/Cassini ATD SN 1987a Suborbital Observations ER-2 Purchase
1990 THROUGH **1994**		CRAF/Cassini Eos SIRTF Solar Probe HRSO* LO* GP-B*	Earth Probes Lifesat	Space Biology Facilities Second-generation Attached Payloads	Laboratory Facilities, Mission Operations and Data Analysis, Theory, Suborbital

*Moderate Mission

IMPLICATIONS OF THE OSSA STRATEGY

The OSSA strategy substantially influences NASA and other agency (domestic and international) programs by generating demands and opportunities in a variety of areas. Within NASA, the appropriate allocation of Agency resources among the various program elements will, therefore, be essential to the success of the OSSA program.

Outside NASA, domestic and international science and applications communities are expected to respond to the leadership embodied in the direction and scope of OSSA's strategy. In addition, the opportunity for NASA to complement its programs through cooperative efforts is expected to continue to grow in areas defined by this strategy.

This section of the OSSA strategic plan provides a summary assessment of the implications of the strategy on other segments of national and international space activities. This first edition of the strategic plan focuses on the NASA program implications, leaving the non-NASA implications for future editions. This section, then, will be updated each year, based on continuing activities to refine our understanding of the implications in each area.

Budget

Using the decision rules described earlier, OSSA has constructed a number of plans that serve to demonstrate that the strategic process does work and that it will permit most programs listed in the previous section to be implemented. For example, if we assume that the growth in the total NASA budget continues over the next several years at its currently planned rate and that OSSA will receive a portion of that budget that is consistent with its historical allocation, then carrying out the ongoing program and initiating most major missions at a rate of nearly one per year will be possible. In some years, however, the initiation of moderate missions rather than major missions may be dictated. Essentially every year, a steady sequence of small missions, Space Station initiatives, and selective augmentations to the research base can also be accomplished. Under a more constrained budget envelope that provides for little growth, the development phase of major missions will be delayed or stretched out over a longer period of time. In this case, however, the initiation of moderate missions at a rate of one per year may still be accomplished.

Transportation

The OSSA strategy assumes the implementation of current NASA plans for a mixed fleet of launch vehicles, including the current Space Shuttle and the full range of existing expendable launch vehicles. A critical performance parameter for the Space Shuttle for Spacelab missions is the maximum permitted downweight. In developing the current strategy, we assume the availability of the Space Shuttle with 230,000 pounds of downweight, which enables Spacelab missions of up to 10 days on Orbiter Vehicle 102, Columbia. (Columbia is the only vehicle that is currently equipped for a 10-day mission. See "In-Orbit Infrastructure" for further discussion.) Launch rates for the Space Shuttle for Spacelab module missions will be two to three per year and for pallet missions one to two per year.

Regarding expendable launch vehicles, implementing the OSSA strategy requires the availability of "small" (Scout-class), "medium and intermediate" (Delta-, Atlas/Centaur-, Titan III-class), and "large" (Titan IV-class) vehicles. Launch rates for expendables will average approximately two small and two to four medium or intermediate per year, with one large required every two to three years.

The rate at which the strategy can be achieved can be substantially enhanced with the Advanced Solid Rocket Motor, which will allow significant increases in payloads delivered to the Space Station manned base during the assembly phase. Without this capability, either delivery of user equipment to the Space Station will be delayed, or additional Shuttle flights will be required. The Advanced Solid Rocket Motor will also enable Space Shuttle-based servicing of polar platforms, provided that Shuttle operations begin at the Western Test Range.

A current deficiency in transportation is the absence of a capability equivalent to that of the cancelled Centaur upper stage in the Shuttle. This capability is required to relieve planetary mission designers of the need to compensate for this deficiency with multiple gravity assist swingbys of Venus and Earth with the attendant costly inefficiency. Until either a heavy-lift launch vehicle equipped with a cryogenic upper stage, or some version of an orbital transfer vehicle combined with a capability for space-based assembly becomes available, planetary orbiters will not be able to achieve efficient direct transfers between Earth and the bodies in the outer solar system.

OSSA, in conjunction with NASA's Office of Space Flight, is engaged in a continuing assessment of civil transportation needs as part of a larger national effort focused on space transportation architecture studies. Each year, the OSSA strategy will form a basis for inputs to these assessments.

In-Orbit Infrastructure

Development of the OSSA strategy assumes the availability of the Phase I Space Station in the mid-to-late 1990s. The early 1990s will be devoted to preparing for the Space Station through experiment and instrument development in space. At the present time, however, the only capability available for manned space operations is the Space Transportation System and its associated Spacelab systems. This matched system enables Spacelab module missions of up to 10 days only three times in a 12-month period and then only on Columbia. Although this capability appears to provide adequate capacity for continuing Spacelab activity after the deployment of the Space Station, demands of both U.S. and foreign users are such that a near-term shortfall in capacity could delay preparations for the Space Station without an increase in available time in orbit through extended duration capability for the Shuttle and augmentation for the Spacelab system.

Several potential enhancements are on the horizon, but they will not be available until 1991 or 1992; these enhancements could include the Extended Duration Orbiter and commercially developed space facilities. Studies currently under way are focused on identifying optimal configurations of these elements, used in conjunction with the Space Transportation System, to both extend and increase the frequency of manned scientific operations in space. By using the commercially developed space facilities in a crew-operated mode, the number of equivalent annual Spacelab flights could be increased. In addition, the duration of Spacelab or commercially developed space facility man-tended missions could be extended to at least 20 and possibly as many as 30 days.

With regard to the Space Station itself, recent OSSA assessments indicate that OSSA could fully subscribe planned resources, even assuming 45 kilowatts of power available to users with the three laboratory modules in the baseline and five to six Shuttle flights per year. Future OSSA programs are likely to benefit from, and indeed may require, the availability of the co-orbiting platform elements of the Space Station. Additional activities are currently under way as part of the Space Station Program Requirements Review to understand and resolve any issues.

The deferral of servicing for free-flying spacecraft and of some capabilities for attached payloads is one of those issues. The reinstatement of the Space Station-based Orbital Maneuvering Vehicle for retrieving co-orbiting spacecraft, along with some limited capability at the manned base for changing out orbital replacement units on free-flyers and for replenishing fuel and cooling cryogen on free-flyers or attached payloads, would substantially enhance planned utilization. Efforts are under way to further define needs in this area.

Telecommunications and Information Systems

The availability of the full range of telecommunications and data systems provided by NASA through its Offices of Space Operations and Space Station is assumed in developing the OSSA strategy. These services include the Tracking and Data Relay Satellite system, the Deep Space Network, the Program Support Communications Network, and the Space Station Information System.

OSSA information systems activities enhance the scientific productivity of NASA research programs through the application of advanced information technology. The information systems program provides an effective scientific computing environment and a comprehensive scientific data service capability to OSSA's widely distributed research community. Key elements of the program include scientific computing and data management support through the NASA Space and Earth Sciences Computing Center and the National Space Science Data Center, both at the Goddard Space Flight Center. Another fundamental element of the program is networking service to expand access and resource sharing throughout the community. A research program in advanced technologies and techniques to develop generic tools and capabilities for subsequent application across OSSA disciplines is also ongoing.

The information systems program has collaborated with individual research disciplines to design and build data systems for the oceans, climate, planetary, and land communities. Some scientific disciplines have already begun to develop disciplinary and interdisciplinary information systems for planned missions, such as the Earth Observing System.

Data and information systems will continue to grow in importance as a vital support element for our scientific programs. The Space Station promises an era of increasingly complex, sophisticated missions comprised of multi-agency, international campaigns. The unique requirements generated by these missions mandate advanced information systems to achieve the full scientific objectives of the era. The associated challenges are numerous; not the least of these is a change in perspective with respect to planning and management.

OSSA intends to evolve from the mode of designing and developing essentially independent data systems for individual flight projects and to broaden the perspective for designing systems and evaluating trade-offs that span payloads, projects, and scientific disciplines. This mode requires a consistent planning model, along with a methodology that can accommodate change to exploit advances in technology throughout the life cycle of the very long duration future flight missions and scientific campaigns.

The Science and Applications Information System is the basis of a strategy for planning and developing future information systems to meet the objectives of all OSSA scientific disciplines. This strategy is composed of four key elements or activities, conducted in close coordination and cooperation with the scientific discipline programs. First, an overall architecture and planning model that meets the basic requirements of OSSA programs will be defined. This architecture must support a highly adaptable environment to permit the incremental, modular evolution of system components. Second, OSSA information system requirements will be synthesized so that these requirements can be clearly represented in the design and development phases of the Space Station Information System and other flight mission data systems. Third, a testbed program will be developed to explore, evaluate, and demonstrate new and emerging technologies to support the telescience and other operational scenarios envisioned in the Space Station era. Where appropriate, these technologies will be integrated into ongoing development efforts. Finally, tools and information system capabilities that can be applied to all of OSSA will be developed.

Technology

In developing our strategy, we assume the availability of technology that is currently the state of the art or near that level. In addition to depending upon continued efforts by the Office of Aeronautics and Space Technology in a wide range of spacecraft and instrument subsystems, OSSA currently is conducting Advanced Technology Development programs for the next four major OSSA initiatives—the Advanced X-Ray Astrophysics Facility, the Mariner Mark II program (CRAF/Cassini), the Earth Observing System, and the Space Infrared Telescope Facility. The Solar Probe mission will present significant new challenges, especially in the area of thermal protection systems; therefore, advanced technology studies in support of this candidate major mission will also need to be initiated. Advanced technology development assures the timely availability of critical technologies well before the need dates for full-scale development. This approach to risk and cost reduction is an important element of the OSSA strategy.

Future OSSA programs will benefit substantially from technologies that are generally associated with sensors, information systems, automation and robotics, and artificial intelligence. Applications include ultrahigh density data storage on the Space Station, autonomous experiment systems operations, telescience, and telerobotic servicing. All these technologies will enhance productivity and will help to extend human presence in low-Earth orbit as well as eventually in geosynchronous orbit.

OSSA is currently involved with NASA's Office of Aeronautics and Space Technology (OAST) in planning the scope and content of activities within the OAST program that are of direct interest to OSSA. A Memorandum of Understanding between OSSA and OAST is being developed to outline the responsibilities of the two offices in the Humans-in-Space element of Project Pathfinder. The Life Sciences Division of OSSA will take the lead in areas relating to human health, performance, and bioregenerative life support systems. OAST will take the lead in advanced technology for extravehicular activity, human factors, and physical-chemical life support systems technology. This plan provides the basis for a mechanism to enhance the dialogue between these offices, thereby serving to introduce new efficiency in the technology transfer process.

Institutions

The successful accomplishment of the OSSA strategy depends on support from the NASA Centers, other federal laboratories, U.S. universities, and the private sector. Internal to the Agency, OSSA has specific institutional management responsibilities for the Goddard Space Flight Center and the Jet Propulsion Laboratory; however, every NASA center is a direct participant in OSSA's science and technology programs, and the continuation of this support is essential. External to the Agency, the ongoing contributions of scientists and engineers at U.S. universities and in industry are critical to the success of all OSSA's programs.

NASA CENTERS

The following descriptions of the roles of the NASA Centers in the OSSA program are intended to identify the nature of the predominant activities of each center. The descriptions are not intended to be exhaustive and are not meant to imply any limitations on participation.

Goddard Space Flight Center. GSFC is involved in virtually all scientific disciplines within OSSA, with the exception of the microgravity sciences (materials and life sciences). Personnel at Goddard have extensive experience in the management of science and applications satellite projects and instruments, including the Explorer program. GSFC is responsible for many critical support functions in the research base, including the operation of the NASA Space and Earth Sciences Computing Center, the National Space Science Data Center, and the sounding rocket and balloon program at the Wallops Flight Facility. In addition, as a complement to GSFC's role as the Work Package 3 Space Station development center, Goddard supports OSSA integrated Space Station utilization efforts in the areas of platforms and attached payloads.

Goddard is also responsible for the management and operation of the Hubble Space Telescope, including the Space Telescope Science Institute, where Hubble Space Telescope scientific data and operations planning will take place. Mission operations for a number of science and applications satellites are also conducted by Goddard. Under the management of the Office of Space Operations, GSFC runs the Tracking and Data Relay Satellite system, which is essential to the operation of all U.S. Earth-orbiting spacecraft.

Jet Propulsion Laboratory. JPL is most often associated with the OSSA solar system exploration program, and indeed, the laboratory is a unique national resource in the development and scientific operation of deep space flight systems. However, JPL also plays a key role in most other areas of observational science and in the development of unique computational capabilities. JPL's role in the development of synthetic aperture radar systems, as well as other instruments, is central to the OSSA Earth science strategy. JPL also plays a limited, but important, role in the microgravity science program, specifically in the area of containerless processing.

Under the management of the Office of Space Operations, JPL operates the Deep Space Network, the worldwide tracking stations for planetary spacecraft.

Marshall Space Flight Center. MSFC has vast experience as a major system development center and, based on this, develops and integrates major flight facilities for OSSA. Current examples include management of the Hubble Space Telescope development and of the proposed Advanced X-Ray Astrophysics Facility, and mission management for most of the Spacelab and Shuttle-attached payloads. Continuation of Marshall's mission management role is critical to OSSA's effective utilization of the manned base of the Space Station complex. Less widely known, but very important, is MSFC's participation in the OSSA science and applications programs, particularly in space physics, astrophysics, Earth science, and microgravity science.

Ames Research Center. ARC is a major participant in the OSSA life sciences program in space physiology, space biology, and exobiology. ARC also has an active role in infrared astronomy, planetary sciences, and Earth sciences, in terms of both scientific research and the operation of the airborne science program (including the Kuiper Airborne Observatory, the ER-2s, the DC-8, and the C-130). In addition, ARC supports OSSA efforts in information systems and telescience for the Space Station.

Johnson Space Center. JSC plays a critical role in the OSSA life sciences activity, particularly in research on the effects of spaceflight on humans. JSC also participates in the solar system exploration program and manages the lunar curatorial facility. In microgravity science and applications, JSC has an ongoing program in biotechnology, as well as in the operation of the KC-135 aircraft, which is used for microgravity experimentation. JSC is also the mission management center for life sciences Spacelab missions and some Earth science and applications activity, including the flight of imaging radar on the Shuttle.

Kennedy Space Center. Because of KSC's operational character, the center's participation in the research program is limited to life sciences, particularly in playing a key role in developing the Controlled Ecological Life Support System. In keeping with its operational expertise, KSC is a major support center for Spacelab payload integration, and a similar role for KSC is expected to evolve in the Space Station era. Additionally, the Kennedy Space Center processes the majority of spacecraft prior to launch on both the Shuttle and on unmanned launch vehicles.

Langley Research Center. LaRC plays a substantial role in the Earth science and applications research program, particularly in the development of satellite experiments and the analysis of observations. LaRC also provides support to the materials science program for Spacelab and Space Station facility systems engineering, and provides fundamental research expertise in space radiation physics.

Lewis Research Center. LeRC is a key participant in the microgravity materials science and applications program, particularly in the areas of combustion and metals and alloys. Lewis also operates a Lear Jet and drop facilities for microgravity simulation. LeRC has the lead role in the communications program, and is responsible for the development of the Advanced Communications Technology Satellite.

National Space Technology Laboratories. NSTL is an important participant in the Earth science and applications program, including operation of the Earth Resources Laboratory, which is involved in research in tropical forestry and archeology.

In concert with the centers, OSSA will assess the current state and future needs of the NASA institutional base. A key first step was the "Center Science Assessment Team" activity conducted in 1987. This study, chaired by D. James Baker of the Joint Oceanographic Institutes, identified strengths and weaknesses in the in-house space science and science-related technology program. NASA is developing a plan of action to address the recommendations of the Baker report.

OSSA plans to develop a companion document to this Strategic Plan, which will articulate the long-term institutional requirements for active center participation. Examples of problems already identified include: shortages in civil service manpower, aging facilities and equipment, a "generation gap" (a decrease in mid-career professionals in the work force), and the need for increased training opportunities in the high-technology fields.

U.S. ACADEMIC INSTITUTIONS

OSSA has traditionally considered the U.S. universities part of its institutional base, and will continue to do so. NASA depends heavily on academia, not only as scientific investigators, but also as educators of the next generation of space scientists. The participation of U.S. universities is essential to maintaining a broad base of capability in areas vital to the future of space science and applications. In its 1986 report, entitled *The Crisis in Space and Earth Science*, the NASA Space and Earth Science Advisory Committee cited a number of issues that are acutely important to the health of universities as key elements of the OSSA program. Among these issues were the need for a spectrum of small and large research opportunities, reliable and frequent access to space, attention to training and development of graduate students, and the stabilizing role of research and analysis. The OSSA strategy explicitly addresses those issues. OSSA intends to continue to work with its advisory bodies to assess the needs of the university community and to devise approaches to ensure that the unique long-term contributions that the community makes to space science and applications continue in the future.

APPENDIX : THE OSSA SCIENTIFIC DISCIPLINES—INDIVIDUAL STRATEGIES

Developing a strategy for the future program of OSSA and its discipline divisions begins in the scientific research community, where active collaboration between OSSA and the community translates goals into strategies for scientific discipline programs. A number of panels of the National Academy of Sciences and the NASA Advisory Council advise OSSA about broad issues of the overall OSSA program. These panels include the Space Science Board, the Space Applications Board, the Space and Earth Science Advisory Committee, the Space Applications Advisory Committee, and the Life Sciences Advisory Committee. These committees and other special ad hoc advisory bodies also specifically address the challenges and charters of each of the scientific disciplines that fall under OSSA's umbrella. Focused groups, such as scientific working groups and project definition teams, provide more specific recommendations regarding near-term strategies. These advisory bodies, and the publications in which their recommendations are elucidated, are listed in each discipline description.

With the recommendations of these advisory groups as detailed objectives, and with the overall goals for space science and applications providing the framework, each scientific discipline formulates specific program plans designed to focus on a particular aspect of the OSSA program. Each Division strives to complement the other six, and each formulates a strategy that can then be integrated into a comprehensive, cohesive plan, which provides a context for decision-making within OSSA.

In the pages that follow, we summarize, for each discipline, the goals and objectives that define its charter, its current situation, the relevant factors of the external environment, and the strategy that will guide its activities for the next five to ten years. The integration of these individual plans is the basis of OSSA's overall strategy.

Astrophysics

The astrophysics program performs those studies and investigations that are necessary to determine the nature of objects and the range of conditions existing within the universe, and to identify their place in and contribution to its evolution. The goals of the program as stated by the Committee on Space Astronomy and Astrophysics of the National Academy of Sciences can be summarized as being centered upon achieving unprecedented understanding of:

The origin and fate of the universe,

The underlying fundamental laws of nature and physics that govern the universe,

The birth and evolutionary cycles of galaxies, stars, and planets.

These goals are pursued through the observation and theoretical interpretation of the characteristic radiation emitted by astrophysical systems. The astrophysics program is structured around four primary objectives: (1) establishment of long-term observatories for viewing the universe in four major wavelength regions of the electromagnetic spectrum (infrared, optical/ultraviolet, X-ray, and gamma-ray bands); (2) attainment of crucial bridging and supporting measurements via directed-objective missions of intermediate and small scope conducted within the Explorer and Spacelab programs; (3) enhancement of scientific access to results of space-based research activities including problem-oriented, multidisciplinary studies implemented through the Astrophysics Data System program; and (4) development and maintenance of the scientific/technical base for space astrophysics programs and missions via the research and analysis and suborbital programs. In addition, an advanced planning activity is conducted to identify and direct the early definition of new mission candidates.

CURRENT SITUATION

The astrophysics program has one active flight project, the International Ultraviolet Explorer, which is in its tenth year of operation. Conducted in cooperation with the European Space Agency, the project supports approximately 230 guest investigators per year.

Developing flight projects, all of which are scheduled for launch in the next three years, begin with the Hubble Space Telescope, the first of the Great Observatories, planned for 15 years of operation. The European Space Agency is providing the solar array and one science instrument. The second of the four Great Observatories is the Gamma Ray Observatory, which will have an operational lifetime of six to ten years. The Gamma Ray Observatory will carry one European instrument on its four-instrument payload; it is expected to be launched in 1990. The Roentgen Satellite, with an operational lifetime of approximately three years, is a Federal Republic of Germany flight program wherein the United States provides a science instrument and launch vehicle, and operations and data analysis are shared; its expected launch date is 1990.

Two Explorer missions are also in development. The Cosmic Background Explorer, with an anticipated 1989 launch date, will investigate the creation of the universe using the oldest information in existence—the cosmic microwave background radiation. Development will also continue on the Explorer Platform and its first payload, the Extreme Ultraviolet Explorer, which in 1991 will begin our first sensitive exploration of the universe at wavelengths between ultraviolet light and X rays.

Although the United States has been the world leader in space astrophysics in the past, the Europeans, the Japanese, and the U.S.S.R. are all conducting increasingly sophisticated advanced programs. Of particular relevance is the Quantum (Kvant) astrophysics module that the U.S.S.R., in cooperation with the Europeans, has placed on the Mir space station. This module is providing remarkable views of deep-space targets several years before the projected launch of the more capable Advanced X-Ray Astrophysics Facility.

The unexpected appearance of Supernova 1987a has provided the opportunity and impetus for a special study by the research and analysis program. This program has provided the basic support for the development of the infrared, ultraviolet, X-ray, and gamma-ray instruments that are being flown on balloons and rockets to observe the supernova, and for the formulation of theoretical models of the expected light curve, which have provided invaluable assistance in planning an optimal observing program.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

The highest priority for astrophysics is the completion of the Great Observatories program (Hubble Space Telescope, Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility, and Space Infrared Telescope Facility), which will provide the backbone for a contemporaneous, coordinated, multispectral observing program. Through the implementation of this program, the United States will be firmly established as the world leader in astrophysics research.

Activities also should be initiated to complete the two current programs of survey and detailed science missions, such as the Extreme Ultraviolet Explorer and the Roentgen satellite, and the special topic investigations, including Gravity Probe-B and the X-Ray Timing Explorer. A very significant enhancement of the capability to use suborbital observations to advance infrared astronomy can be achieved by modifying a Boeing 747 aircraft to carry the Stratospheric Observatory for Infrared Astronomy (SOFIA).

Finally, definition should be under way to select, study, and develop the next generation of Scout- and Delta-class Explorers such as the Far Ultraviolet Spectroscopy Explorer and the Nuclear Astrophysics Explorer.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Committee on Space Astronomy and Astrophysics
Space Science Board
National Academy of Sciences
National Research Council

A Strategy for Space Astronomy and Astrophysics for the 1980's (1979).

Institutional Arrangements for the Space Telescope—a Mid-Term Review, Space Telescope Science Institute Task Group (1985).

The Explorer Program for Astronomy and Astrophysics (1986).

Long-Lived Space Observatories for Astronomy and Astrophysics (1987).

Astronomy Survey Committee
Space Science Board
National Academy of Sciences
National Research Council

Astronomy and Astrophysics for the 1980's (1982).

Solar System Exploration

The fundamental goals and approaches of the solar system exploration program are those recommended by the National Academy of Sciences' Committee on Planetary and Lunar Exploration and endorsed by the Solar System Exploration Committee of the NASA Advisory Council. Briefly stated, the goals are:

Origin and Evolution: To determine the present nature of the solar system, its planets, and its primitive bodies, in order to understand how the solar system and its objects formed, evolved, and (in at least one case) produced environments that could sustain life.

Comparative Planetology: To better understand the planet Earth by determining the general processes that govern all planetary development and by understanding why the "terrestrial" planets of the solar system are so different from each other.

Pathfinders to Space: To establish the scientific and technical data base required for undertaking major human endeavors in space, including the survey of near-Earth resources, the characterization of planetary surfaces, and the search for life on other planets.

The planetary exploration program is structured around the recommendations of the Solar System Exploration Committee, which stress continuity, commonality, cost-effectiveness, and the use of existing technology. The Core Program recommended by the SSEC consists of: (1) a continuing series of modest Planetary Observer missions to explore inner planets and near-Earth asteroids using reconfigured off-the-shelf Earth-orbital spacecraft; (2) a continuing series of Mariner Mark II spacecraft missions to explore the outer planets, comets, and asteroids, using a common spacecraft with evolving technological capabilities; (3) development of a multi-mission spaceflight operations and data analysis capability; and (4) strong foundations of ground-based research, analysis, and related activities funded at about 25% of the total program. The SSEC separately (in 1986) recommended an Augmented Program of more challenging missions to return samples from a comet and from the surface of Mars, and to begin the search for other planetary systems.

CURRENT SITUATION

By the end of this decade, all the major planets and their satellites will have been studied at the reconnaissance (i.e., flyby) stage. The exploration phase has either been completed or has been established for every major solar system body that is accessible to us. Two spacecraft launched in the 1970s, the Pioneer Venus Orbiter and Voyager 2, are still in operation. Pioneer recently completed its 3,000th orbit of Venus, and Voyager 2 is heading for an encounter with Neptune in 1989; it will then travel on to study interstellar space. The stage is set to continue intensive study of the Moon and Mars. Finally, emerging developments in telescope technology now enable serious planning for the detection of extra-solar systems.

Progress toward realizing the basic premise of the SSEC, national commitment to a continuous, but modest cost level of program activity, has been slow. Only the first two recommended missions, Magellan and Mars Observer, have been approved for project start. The Congress has approved the Planetary Observer concept, but the Mariner Mark II missions still await adoption. NASA has implemented the multi-mission operations concept but research and analysis activities remain funded at only a small fraction of the total program budget.

The Challenger accident and the subsequent cancellation of the Shuttle-Centaur upper stage have both had a drastic impact on the planetary program. Both Galileo and Magellan have been delayed; these delays have had a concomitant impact on the program's budget by diverting resources that had been expected to support research and new program development to, instead, cover continued engineering attention to grounded spacecraft. And the absence of an energetic upper stage necessitates complex gravity-assist trajectories and much longer trip times for missions to the outer planets.

During the past decade, other nations have made or planned major advances in solar system exploration. The European Space Agency, Japan, and the Soviet Union all launched spacecraft to Comet Halley; the U.S. provided critical ground support. And although the U.S. continues to maintain an overwhelming lead in exploring the outer planets, the U.S.S.R. has made impressive accomplishments in exploring Venus and has announced an ambitious program for the exploration of Mars.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

The highest priorities for solar system exploration are the implementation of the Mariner Mark II program and the initiation of the Lunar Observer, the second in the Planetary Observer series. The Mariner Mark II program begins with the technically mature Comet Rendezvous Asteroid Flyby, followed by the Cassini mission to Saturn and Titan; both are missions that allow us to maintain leadership in outer solar system exploration. In addition, major increases in research and analysis funding, especially to equip laboratories, are anticipated. Another element of the strategy is the development of Earth-orbital planetary facilities.

The program also plans to take advantage of the Hubble Space Telescope in the near term as well as using the Space Station over the longer term. The Cosmic Dust Collection Facility will be among the first Space Station-attached payloads. Earth-orbital facilities (e.g., Astrometric Telescope Facility, Circumstellar Imaging Telescope) will also be used in the search for extra-solar planetary systems over a decade's time. Where practicable, the program will seek to collaborate with other spacefaring nations to gain increased program content at advantageous cost.

Our current and future plans now place a high priority on launch and mission risk reduction; we have begun a policy of acquiring spare subsystems to enable rapid changeout during development testing to protect launch windows and we are designing and spacing future missions to provide the maximum possible backup for missions now under development. One example of this new approach is the purchase of spare components for the Mars Observer mission, in order to insure the timely launch of that mission and to initiate subsequent Planetary Observer missions.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Committee on Planetary and Lunar Exploration
Space Science Board
National Academy of Sciences
National Research Council

Strategy for Exploration of the Inner Planets: 1977-1987 (1978).

Strategy for Exploration of Primitive Solar-System Bodies—Asteroids, Comets and Meteoroids: 1980-1990 (1980).

A Strategy for Exploration of the Outer Planets, 1986-1996 (1986).

Advanced Instrumentation for Planetary Exploration (in press).

A Strategy for the Detection of Extra-Solar Planetary Material (target availability, 1988).

Joint Working Group—NAS/ESF
National Research Council

Report of the NAS/ESF Joint Working Group: A Strategy for U.S./European Cooperation in Planetary Exploration (1986).

Solar System Exploration Committee
NASA Advisory Council

Planetary Exploration through Year 2000: Part One: A Core Program (1983).

Planetary Exploration through Year 2000: Part Two: An Augmented Program (1986).

Space Physics

Space physics involves scientific investigations into the origin, evolution, and interactions of space plasmas in a wide variety of astrophysical settings. The goal of the discipline, endorsed by the Committee on Solar and Space Physics of the National Academy of Sciences, is to advance knowledge of:

The ionosphere and magnetosphere of the Earth and other planets, as well as the heliosphere, in their quiet (steady state) as well as dynamic configurations,

The Sun, both as a star and as the dominant source of energy, plasma, and energetic particles in the solar system,

The acceleration, transport, and propagation of energetic particles that originate both within the solar system and outside it (i.e., solar and galactic cosmic rays).

Measurements of space plasma systems and plasma processes are obtained by probes situated within the plasma systems, such as a magnetosphere or the heliosphere; by remote sensing of regions not directly accessible to probes, such as the solar surface, and of regions requiring a global view, such as the Earth's auroral zone; and by cosmic ray probing of extra-solar system phenomena. These measurements are complemented by active plasma experiments performed both in the laboratory and in accessible space plasmas, such as Earth's ionosphere, and by measurements obtained from instruments deployed on free-flying satellites, Shuttle payloads, sounding rockets, and balloons. Theory and computer simulations synthesize these measurements into a general understanding of space physics phenomena, including geospace, solar/planetary interactions, the solar system, and the chemical evolution of the galaxy.

CURRENT SITUATION

Spaceflight programs sponsored by OSSA and foreign space agencies have provided opportunities for the initial reconnaissance of a variety of planetary atmospheres, ionospheres, and magnetospheres, the heliospheric region, and the layers of the solar atmosphere. Measurements from this survey, which is now nearly complete, have been made over wide ranges of wavelength, energy, and field strength. They have led to the identification and classification of many plasma phenomena and to some understanding of cause and effect relationships.

Currently, five spacecraft are collecting valuable scientific information about the Sun, the interplanetary medium and the cosmic rays penetrating this medium, geospace, and Sun-Earth interactions. These satellites, all supported by the continuing Mission Operations and Data Analysis budget, are the Solar Maximum Mission, International Cometary Explorer, Interplanetary Monitoring Platform, Charge Composition Explorer, and Dynamics Explorer.

The launch of Ulysses, which will study the heliosphere out of the ecliptic plane, is planned for 1990. Moderate missions in development include the Combined Release and Radiation Effects Satellite, scheduled for launch in 1990, to provide mapping of the radiation belts during solar maximum and to analyze ionosphere/magnetosphere chemistry through numerous chemical releases. The Tethered Satellite System with a diagnostic satellite tethered on the end of a 20-kilometer conducting wire is planned for a 1991 Space Shuttle mission to investigate electrodynamic plasma effects at induced voltages of about 5 kilovolts. Further detailed measurements of the Sun are planned with the Spartan-201 white light coronagraph and UV coronal spectrometer in 1990-1991 and, cooperatively with the Japanese, the Solar-A soft and hard solar X-ray measurements.

The International Solar Terrestrial Physics (ISTP) program is the next major flight program. It encompasses the Global Geospace Science program, which includes the NASA Wind and Polar satellites and the Japanese Geotail mission. The Wind and Polar spacecraft will, in combination with Geotail, investigate geospace as a system. Another element of the ISTP program is the Collaborative Solar Terrestrial Research Program, which includes the Solar and Heliospheric Observatory and Cluster missions, conducted jointly with the European Space Agency.

NASA has previously maintained a leadership role in the conduct of space physics research, albeit with significant support from international partners. It is increasingly becoming the case, however, that European, Japanese, and U.S.S.R. scientists have comparable capabilities. The U.S. space physics community is currently benefiting from an unprecedented level of international cooperation, which will allow the collaborative accomplishment of scientific objectives unattainable by any individual national organization.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

The highest priority major mission for space physics is the Solar Probe, which will be humanity's first direct exploratory venture to the vicinity of the Sun. This mission offers a unique opportunity for leadership in this area; because of this and also because of its significant scientific benefit, the Solar Probe has been strongly endorsed by the scientific community.

The highest priority moderate mission for space physics is the High-Resolution Solar Observatory, a scientific platform for performing investigations of the Sun's fine-scale magnetic structures. This program is unusually mature in terms of hardware definition, and the provision of funding for its construction and implementation is critical.

Other programs, such as Space Station-attached payloads and Explorer missions, such as the Advanced Composition Explorer, with support from rocket and balloon programs and theory and analysis programs, can also fulfill many space physics objectives.

As we move beyond the simple reconnaissance of various space plasma phenomena, the support of in-depth data analysis and sophisticated theory building becomes increasingly important. The research and analysis budget needs to be augmented in advance of flight missions to provide guidance in terms of instrument selection and to support science operations. Data analysis budgets need to track the flight operations budgets to ensure a commensurate research effort. Because of the increasing movement within the field from simple data collection into synthesis and model building, we anticipate a need for enhanced support of theory activities over the next five years.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Committee on Solar and Space Physics
Space Science Board
National Academy of Sciences
National Research Council

Solar-System Space Physics in the 1980s: A Research Strategy (1980).

An International Discussion on Research in Solar and Space Physics (1983).

A Strategy for the Explorer Program for Solar and Space Physics (1984).

Space Physics: An Implementation Plan for Priorities in Solar System Space Physics (1985).

Joint Data Panel of the Committee on Solar-Terrestrial Research
Space Science Board
National Research Council

Solar-Terrestrial Data Access, Distribution, and Archiving (1984).

Panels of the Space Science Board
National Research Council

The Physics of the Sun (1985).

Earth Science and Applications

The overarching goal of Earth science and applications has been succinctly formulated by the Earth System Sciences Committee of the NASA Advisory Council, and is as follows:

Obtain a scientific understanding of the entire Earth System on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales.

Thus, it is necessary to establish global observations and studies directed at understanding the responsible physical, chemical, and biological processes that operate to unify the Earth environment as a system. To model the Earth and predict the future course of the environment, Earth science and applications must document the changes that are occurring now or will occur in this system over coming decades. The challenge to Earth science is to develop the capability to predict those changes that will occur on time scales of decades to centuries, whether they derive from natural causes or are linked to human activity.

The discipline supports the development and use of quantitative models of elements of the Earth system that can be used to anticipate, for example, future global trends in climate, Earth resources, and ocean productivity. The development of research and operational sensors ensures that continuing data sets can be derived, assessed, and (where appropriate) transferred into the private sector or to other federal agencies. Supporting both research and development is the formation of a data and information system through which scientists and operational users can assemble the information essential for research and for effective environmental decision-making. Long-term reliability, availability, and consistency in data sets are critical to research, operational, and commercial users of remote sensing.

CURRENT SITUATION

Traditionally, the Earth science disciplines have advanced through studies of the individual components: interior, crust, biosphere, oceans and ice cover, atmosphere, and ionosphere. Recent research has clearly demonstrated that land, atmospheric, ionospheric, oceanic, and biospheric processes are strongly coupled. To understand our environment, and ultimately to predict global change induced either naturally or by human activity, it is important to study the Earth as a single coupled system, as well as to answer questions arising in such separate disciplines as ecology, biology, meteorology, hydrology, geology, oceanography, and atmospheric chemistry. The Upper Atmosphere Research Satellite, which will study the chemistry and dynamics of the stratosphere and mesosphere; TOPEX (the Ocean Topography Experiment), which will map the global circulation of the oceans; and the Earth Radiation Budget Experiment comprise major steps forward in some of these areas.

In the mid-1990s, we expect to begin having access to a new generation of advanced polar platforms, which will greatly extend our research capabilities because they will support an expanded set of co-located instruments. The opportunity to service, modify, and replace instruments in orbit should make it possible to sustain consistent, uniformly calibrated, long-term measurements.

We are currently studying the Earth Observing System, to be carried out in conjunction with the National Oceanic and Atmospheric Administration's operational program on the Space Station Polar Platforms. This system will, for the first time, allow us to acquire the long-term, self-consistent data sets needed for understanding and predicting global change. The planned Earth Observing System instrument complement has been extensively discussed with working groups of the Earth System Sciences Committee and was found to meet the anticipated requirements of Earth System Science in the 1990s.

The Announcement of Opportunity for the Earth Observing System was released in mid-January 1988. Concurrent with this release, the European Space Agency and the Science and Technology Agency of Japan have released coordinated announcements soliciting payload development for the European Polar Platform and the Japanese instruments on the NASA Space Station platform. Instruments to fly as attached payloads on the manned Space Station are also being solicited by this Announcement of Opportunity.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

The Earth Observing System represents a major element in the U.S. contribution to the International Geosphere-Biosphere Program. The Earth System Sciences Committee has stated that the Earth Observing System is the centerpiece of its strategy for NASA. The Earth Observing System provides a context within which to promote the more focused research projects that are necessary to maintain program vitality.

Missions such as the proposed Mesosphere and Lower Thermosphere Explorer, and a dedicated series of small missions, called Earth probes, which are of a class similar to the missions of the Explorer program, would provide a complement to the observations carried out by the Earth Observing System. The aircraft observation program for remote sensing of Earth has also proven very useful, and enhancement of the fleet's capabilities and utilization is planned.

The foundation for large observatory missions is the direct heritage of aircraft and Shuttle payloads development. Sustained Shuttle payload activity, such as the Atmospheric Laboratory for Applications and Science series, needs to continue.

Earth science has always pursued revolutionary advances in our ability to observe, model, understand, and predict the future of the Earth. In Earth science and applications, major technological and intellectual breakthroughs must be a part of a long-term sustained effort to consistently measure our environment. But scientific analysis and instrument development must have a traceable heritage of successful, yet increasingly more complex implementations. To this end, it is important to maintain continuity in all aspects of environmental observations from space and to assure that calibration is maintained as techniques and devices improve.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Committee on Earth Sciences
Space Science Board
National Academy of Sciences
National Research Council

A Strategy for Earth Science from Space in the 1980's, Part I: Solid Earth and Oceans (1982).

A Strategy for Earth Science from Space in the 1980's, Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota (1985).

Earth System Sciences Committee
NASA Advisory Council

Earth System Science: A Program for Global Change (1986).

Life Sciences

The life sciences discipline is involved in all aspects of NASA's activities in space exploration. The program has three major goals, derived from NASA's charter and endorsed by the Committee on Space Biology and Medicine of the National Academy of Sciences:

Understand the origin, evolution, and distribution of life in the universe.

Understand the relationship between life and gravity and other planetary properties.

Develop medical and biological systems that enable the human exploration and habitation of space.

The life sciences program extends from basic research to applied clinical practice. Major disciplinary areas of research include operational medicine, space medicine, space biology, global biology (biospherics), exobiology, and Controlled Ecological Life Support Systems.

Major objectives for the space life sciences program elements are to: understand the physiological, sociological, and psychological implications of spaceflight and return to a gravity field; develop appropriate medical and bioregenerative life support technologies to enable human expansion into the solar system; understand the effects of gravity on the life cycles of animals and plants; characterize the combined effects of microgravity, space radiation, and other environmental stresses on biological systems; determine how biological and planetary processes interact; trace the history of biologically important molecules from synthesis to assimilation into planetary and living systems; and undertake the search for evidence of extraterrestrial life.

The life sciences program combines Earth-based laboratory research with on-orbit basic and applied research on a variety of animal and plant species, as well as human beings. This research must use statistically significant numbers of suitable species with experiment replication for data verification and precise control of the primary variable. Experimental exposure of subjects for significant portions of individual life span or multiple generations is a requirement of such research. The exobiology and biospherics elements of the life sciences program use planetary exploration spacecraft and Earth observing satellites, in addition to ground-based studies, to understand the processes that led to the origin of life, and to study the continuing reactions between planetary environments and life. The Earth-based research is conducted in NASA laboratories and in extramural programs centered on university-based individual Principal Investigators and Centers of Research Excellence.

CURRENT SITUATION

Recently, the individual elements of the life sciences program have been closely examined by external review panels, and long-term strategic plans for life sciences programs are being developed by a special committee of the NASA Advisory Council. Implementation of recommendations made by these panels has been initiated.

The life sciences program has depended upon international cooperation to meet several of its objectives (such as Primate Research facilities and unmanned biological satellites) and has developed active working relationships with Japan, West Germany, France, Canada, the European Space Agency, and the U.S.S.R.

While the U.S.S.R. has captured world headlines with lengthy manned missions and has accumulated considerable operational experience in long-duration manned spaceflight, the actual levels of biomedical and biological research data generated from these missions have been limited. The life sciences program is building from a data set established during the Skylab era and supplemented with observations performed during the 24 successful Space Shuttle flights. Planned Spacelab and Space Station research activities will firmly maintain the leadership of the U.S. program.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

The Space Station offers a unique opportunity for the development of leadership in life sciences research. The on-orbit Space Station facilities would initially focus on basic biomedical research to understand the various mechanisms responsible in adaptation to weightlessness and the physiological problems encountered upon return to Earth. To meet Agency operational objectives, an extended-duration crew certification program extending crew stay times to six months or more on the Space Station will encompass a program to enhance physiological countermeasures, making these countermeasures fully operational. On-orbit artificial gravity centrifuges will enable small animal and plant research subject control, initiation of variable-gravity studies, and an opportunity to test artificial gravity as a possible countermeasure for human physiological deconditioning during long-duration spaceflight. Space Station facilities will also serve to confirm the feasibility of establishing a fully bioregenerative life support system for use on future lunar or Mars base operations.

Lifesat, an autonomous free-flying biosatellite program capable of 20 to 40 days duration, is being studied as a complement to the continuing Spacelab series and the space biology facilities on the Space Station. This combination will result in the elaboration of a rigorous program of basic biological science to be matched with optimum flight capability. Further, life sciences will carry out fundamental research in exobiology and biospherics, also utilizing the Space Station as well as the Earth Observing System, the Great Observatories, and solar system exploration missions.

Basic research on the problems concerning human health, safety, and performance must continue with an augmented base, both on the ground and in space. Improving the intramural and extramural base in fundamental basic research is also essential. By establishing a dual system of independent Principal Investigator grants and critical mass teams focusing on special topics or facilities both inside and outside NASA laboratories and in cooperation with the National Institutes of Health, the science management infrastructure will be improved.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Committee on Space Biology and Medicine
Space Science Board
National Academy of Sciences
National Research Council

Life Beyond the Earth's Environment — The Biology of Living Organisms in Space (1979).

A Strategy for Space Biology and Medical Science for the 1980s and 1990s (1987).

Committee on Planetary Biology and Chemical Evolution
Space Science Board
National Academy of Sciences
National Research Council

Origin and Evolution of Life — Implication for the Planets: A Scientific Strategy for the 1980s (1981).

Planetary Biology and Chemical Evolution: Progress and Future Directions (target availability, 1988).

Committee on Planetary Biology
Space Science Board
National Academy of Sciences
National Research Council

Remote Sensing of the Biosphere (1986).

Life Sciences Strategic Planning Study Committee
NASA Advisory Council

Exploring the Living Universe (in press).

Microgravity Science and Applications

The microgravity science and applications program fosters the development of near-Earth space as a national resource by exploiting microgravity and other unique attributes that may be attained in an orbiting spacecraft. The goals of the program are to:

Advance understanding of the fundamental science that governs processes on Earth, in the solar system, and in the universe.

Increase understanding of the influence of gravity on Earth-based processes, leading to better control strategies to improve such processes.

Pursue limited production of exotic high-value materials with enhanced properties to serve as benchmarks for comparison with Earth-based technologies or for highly specialized applications.

Evolve processes for the eventual commercial production of certain high value-added products in space.

Explore the possibility of processing extraterrestrial materials.

To achieve these goals, it is necessary to develop the requisite infrastructure to facilitate the efficient use of the near-Earth space environment by researchers from the academic community and industry.

The elements of the microgravity science and applications program are: (1) fundamental sciences, which includes the study of the behavior of fluids and of transport phenomena in microgravity, and experiments that use the enhanced measurement precision possible in microgravity to measure physical properties and to challenge contemporary theories of relativity and condensed matter physics; (2) materials science, which includes the processing of electronic and photonic materials, of metals, alloys, and composites, of glasses and ceramics, and of polymers, to obtain a better understanding of the role of gravity-induced effects in the processing of such materials with the goal of effecting better control strategies here on Earth; and (3) biotechnology, which primarily studies the growth of protein crystals and the development of separation techniques for biological materials.

CURRENT SITUATION

Currently, the microgravity flight program uses three different capabilities of the Space Shuttle system for accommodation of flight experiments: the orbiter mid-deck, the Materials Science Laboratory, and the Spacelab. Although the general public and the Congress are very interested in the scientific, technological, and commercial potential of the space environment, past budgets, priorities, and flight opportunities have severely restricted the microgravity program. Renewed emphasis within NASA and competition from foreign government-supported programs challenge us to aggressively pursue development of the space environment as a national resource.

A number of recent NASA-sponsored program reviews have argued vigorously for an expanded ground-based program, a sounding rocket program, and the development of hardware that can be readily adapted to various platforms, including the Spacelab, commercially developed space facilities, the Space Station, and possible free-flyers. In addition, OSSA has been charged with supporting user hardware development and with balancing flight manifesting priorities for both academic and industrial researchers.

The delay in the flight program resulting from the Challenger accident has allowed us to restructure the microgravity program. Much of the old hardware that had been adopted from the pre-Shuttle sounding rocket program has been retired and new hardware development has been initiated. The flight program has been thoroughly reviewed to prioritize the highest quality experiments. The most efficient and effective use of limited flight opportunities will be assured by coordinating flight manifest priorities with the development of state-of-the-art flight hardware that can be adapted to the available space platforms.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

The future centerpiece for microgravity science and applications is the Space Station, which will serve as a national microgravity laboratory. For the first time, we will be able to conduct experiments in an interactive mode and feed the results of one set of experiments into the next set in a timely manner. Also for the first time, adequate power will be available to support materials science experiments involving high temperature and the growth of large diameter crystals.

During the next 10 years, we will see the transition of microgravity science and applications research from the Space Shuttle to the Space Station. During that time, the program will evolve through the use of Spacelab to the full utilization of the Space Station. We are initiating a new series of Spacelab flights to regain the U.S. competitive advantage in microgravity and to evaluate Space Station hardware concepts, alternating U.S. microgravity laboratory flights with international microgravity laboratory flights. In addition, our strategy is designed to take maximum advantage of the benefits associated with the use of commercially developed space facilities, should they become available.

While Spacelab continues to present opportunities to conduct and refine Space Station capabilities, the Space Station itself will dominate the future of microgravity science. A ten-year strategic plan has been formulated to guide our evolutionary development of its use. A strategic planning board for microgravity materials science should be established to continue to evaluate and improve this plan.

To delineate the potential advantages and limitations of the space environment, a fundamental requirement is the establishment of a data base that is both relevant and accessible to the user community. Furthermore, that user community should be expanded to include researchers sponsored by industry and other Government agencies; this ensures a broader perspective and enhances the quality and reliability of results. The expansion of the ground-based research program would also increase the base of information for a high-quality scientific program.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Subcommittee on Microgravity Science, Applications, and Commercialization
Space Applications Advisory Committee
NASA Advisory Council

General Program Review and Recommendations Regarding the Microgravity Centers (1987).

Microgravity Materials Science Assessment Task Force
NASA Headquarters

Microgravity Materials Science Assessment Task Force Final Report (1987).

Microgravity Science and Applications Review Committee
Universities Space Research Association

Review of Microgravity Science and Applications Programs, January-March 1987 (1987).

Communications and Information Systems*

The communications research program focuses on developing the high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of future space communications systems. The goal of the program is to:

Maintain United States technological and economic preeminence in space communications and to enable innovative services in support of the satellite communications industry, NASA's needs, and the needs of the public sector.

The program is structured around the development of advanced technology to more effectively use frequencies and the geosynchronous orbit. This research reduces adoptive risk by industry and improves its competitive posture in the world marketplace. The use of sophisticated communications technology also enables new scientific advancement through extremely efficient wideband space communications. Scientific advancement, in turn, enables and enhances future near-Earth and space exploration missions. The communications program also develops positions and supports U.S. and NASA interests in international and domestic communications regulatory forums. The program uses NASA's resources to provide consultation, perform system studies, and plan and conduct space experiments in support of other Government agencies.

CURRENT SITUATION

Although the U.S. has enjoyed leadership in the satellite communications area for several decades, the increased activities of other nations are now challenging this leadership. The Japanese and the Europeans, in particular, have mounted aggressive campaigns to achieve excellence in the communications industry.

The Advanced Communications Technology Satellite program is the centerpiece of our activities in support of U.S. industry. The system includes revolutionary technologies that will lay the foundation for the next generation of commercial service. The steerable and spot beam antennas, together with on-board processing, provide full networking flexibility throughout the hemisphere and provide the capability for high bit rate communications to small terminals.

SARSAT, the Satellite-Aided Search and Rescue program, has already been credited with saving over 1,000 lives. The program is a joint effort of NASA, the National Oceanic and Atmospheric Administration, the Coast Guard, and the Air Force. NASA is responsible for research and development activities. Five satellites are now in service, two from the U.S. and three from the U.S.S.R. A third U.S. satellite is to be placed in orbit in the spring of 1988. The current SARSAT ground system consists of six mission control centers in the U.S., Canada, France, Norway, the U.S.S.R., and Great Britain. Fourteen local user terminals will be in operation by the end of the second quarter of 1988. During 1988, an experiment using geostationary satellites to provide for more nearly instant alerting and identification will be performed. Efforts in the coming year will continue to improve the location accuracy of the system, and to reduce false alarms and the cost/performance ratio of emergency beacons.

The Optical Communications Program has as its focus the flight testing of systems to support future NASA missions as well as the space demonstration of this technology to reduce its adoptive risk by the American space communications industry. This technology will both enhance and enable new science through increased data gathering, transceiving, and processing capability. For example, optical communications, with the advantages of unutilized spectrum and virtually unlimited bandwidth, will enable the enhancement of both near-Earth and deep space exploration missions through the

*The discussion of Information Systems may be found earlier in this document; only Communications are discussed here.

use of telepresence and, therefore, telescience. In addition, operating in the optical spectrum, with its inherently narrow beams and lack of radio frequency interference, makes it an ideal communications technology for use in regions of high density radio frequency communications such as Space Station. The Optical Communications Program will develop the technology to a mature operational status and will support its adoption by the space communications community.

Mobile satellite activities that are being undertaken in close coordination with industry are progressing well, with essentially all of the technology developments scheduled for completion by the end of 1988; some of this hardware is now undergoing field testing. We will also be investigating the feasibility of a flight experiment to validate the large, multibeam antenna technology needed for future mobile and personal communications satellite services. Such an endeavor has been strongly supported by industry and could be carried out in conjunction with the Space Station. A major government-industry conference for facilitating the transfer of technology is scheduled for May 1988.

This program, including the effort to obtain operational frequencies, has served as a focal point to accelerate the introduction of mobile satellite service in the U.S. A single private consortium has now been formed and is currently preparing a filing to the Federal Communications Commission to provide mobile satellite service in the U.S. Licensing approval to own and operate such a system could be granted within months with satellite launch in the early 1990s.

STRATEGY TO BE PURSUED FOR NEXT 5-10 YEARS

Communications research will continue to focus on developing the high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of future space communications systems. These developments, building on the Advanced Communications Technology Satellite and mobile satellite technologies, will enable future satellite communication systems to provide high capacity information services at lower costs to smaller terminals for both fixed and mobile commercial and scientific applications. In addition, we plan to expand our optical link developments that have the potential to greatly increase the rate of information that can be returned from deep space missions, and to interconnect commercial satellite systems.

Personal access communications is a candidate area for the strategic plan. This technology extends mobile communication to its ultimate form, i.e., direct to the person two-way data and voice communications, using a very low-cost hand-held transceiver. The implementation of this technology depends heavily on the development and checkout of electrically large spacecraft antennas. Antennas of this type would use the Space Station as a staging base for deployment and checkout before placing them in final orbit.

The ongoing Search and Rescue program will be evaluated to determine techniques for improving accuracy, decreasing false alarm rates, and making the service available to a broader spectrum of users.

ADVISORY COMMITTEES AND RELEVANT REPORTS

Communications Subcommittee of the Space Applications Advisory Committee
NASA Advisory Council

Communications Satellites: Guidelines for a Strategic Plan (1987).

Committee on Data Management and Computation
Space Science Board
National Academy of Sciences
National Research Council

Data Management and Computation — Volume I: Issues and Recommendations (1982).

Issues and Recommendations Associated with Distributed Computation and Data Management Systems for the Space Sciences (1986).

Space Applications Board
National Research Council

NASA Space Communications Research and Development: Issues, Derived Benefits, and Future Programs (in press).